18(1) 231-240, Spring 2026

Journal of Animal Environment

(E-ISSN 2717-1396, ISSN 2717-1388)

Journal homepage: http://www.aejournal.ir

Original Research Paper

Seasonal Resource Fluctuations Determining Movement Patterns and Group Dynamics of Semi-Arid Herbivore Populations

Dr. Ankita Nihlani[1*], Dr. Nishtha Sharma[2]

[1]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.*
Email: ku.ankitanihlani@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0002-7447-8544
[2]Assistant Professor, Kalinga University, Naya Raipur, Chhattisgarh, India.
Email: ku.nishthasharma@kalingauniversity.ac.in, ORCID: https://orcid.org/0009-0006-4689-2712

Key Words

Semi-arid rangelands, Herbivore movement ecology, Seasonal resource fluctuations, Group fission-fusion dynamics, Forage availability modeling, Spatial tracking telemetry, Adaptive rangeland conservation.

Abstract

The semi-arid ecosystem is known to have very unpredictable spatial and temporal fluctuations in water availability and primary production, thus compelling native herbivores and those raised domestically to constantly modify their behavior. This paper aims to demonstrate how the changes in the availability of resources over the seasons define the movement monitoring, habitat selection, and social dynamics of herds. By applying the technique of combining remote sensing indexes of plant growth, satellite global positioning systems, and direct observation of groups, we studied changes in the behavioral patterns between wet and dry seasons. The outcome of our study showed that the seasonal tactics used were deliberate, as the wet season provided more food for herbivores to form large fission-fusion groups traveling fast over extensive areas; however, the dry season led to clustering within small areas near water sources and resource-driven group formation. The statistics confirmed that primary vegetative mass and distance to the source of water accounted for more than seventy-five percent of the variation in herd migration steps and size. Moreover, population-level modeling showed that increased rain fluctuations are a risk for traditional migration routes and waterhole disease transmission. Overall, the above observations prove that semi-arid large herbivores have a flexible, non-linear behavior in response to weather extremes, which is crucial from an ecological perspective to develop any adaptive management framework of rangelands, safeguard movement routes, and sustain pastoral livestock production systems amid ongoing climate disruptions.

* Corresponding Author's email: ku.ankitanihlani@kalingauniversity.ac.in
Received: 11 December 2025; Reviewed: 19 January 2026; Revised: 03 February 2026; Accepted: 10 April 2026
(DOI): 10.70102/AEJ.2026.18.1.20

Introduction and Foundations of Semi-Arid Resource Dynamics

Semi-arid ecosystems include some of the most unstable environments on Earth, characterized by structural water scarcity, lower than average annual rainfall, and highly unpredictable temporal changes in primary productivity. In such sensitive areas, populations of large herbivore mammals and domesticated livestock face constant challenges in balancing their metabolic needs with an ever-changing matrix of limited environmental resources and other threats. Seasonally changing environmental conditions that result in periods of growth and recession in the availability of palatable food and water become the key parameter influencing the behavioral strategies of these species. Investigating how environmental factors influence daily spatial and social behavior in semi-arid populations becomes a key task in the global conservation agenda for drylands. The current research aims to fill important knowledge gaps related to the understanding of specific behavioral strategies that allow herbivores to cope with starvation and drought at localized scales and affect larger population dynamics.

The present study makes multiple distinct contributions in the realm of dryland ungulate behavioral ecology and sustainable pastoralism. To begin with, the paper develops an innovative framework whereby the speed of movement and the size of the social herd are regarded not as fixed characteristics but rather as dynamically interlinked responses to non-linear changes of vegetation quality. Secondly, it demonstrates how the data obtained through remote sensing techniques can be combined with behavioral tracking of individual animals in order to reveal how human-related habitat fragmentation and alteration of climatic patterns lead to deterioration of traditional animal migration corridors as well as pastoral routes.

The manuscript has a systematic flow of seven parts that solve these ecological relationships. After this introduction, Section 2 reviews recent advances in remote sensing, range fidelity, and ungulate behavior. In Section 3, we describe the tracking methods and the analytical models applied. In Section 4, we present the empirical results and tables of data illustrating the seasonal shifts. Finally, Section 5 discusses conservation implications and climate vulnerability, Section 6 provides a practical field guide, and Section 7 outlines strategic research priorities in conclusion.

Literature Survey

There have been significant developments in the scientific understanding of the ecology of herbivores in drylands, owing to advancements in the field of satellite telemetry and spatial analysis. The initial focus was on movement patterns at the macro-level among animals, which established that there are movements of large herbivores to areas characterized by seasonal flushes of vegetative biomass to maximize their nutrition (Boone et al., 2008). For both the wild and pastoral environments of today, these traditional movement patterns face increased pressure in the wake of climate change, which creates baseline shifts and contributes to climate-induced zoonotic pathogens (Reginald, 2024). In terms of modern movement ecology, it has been shown that ungulates do not follow random movement patterns but adapt in an efficient manner to reconcile patchy resources and predation and temperature risks (Martin et al., 2015). It is necessary to use spatial metrics for such changes, and current research has emphasized the effectiveness of multi-temporal difference in vegetation indices to identify such changes.

Empirical evidence from recent times also discredits historical assumptions about home range uniformity in large animals inhabiting drylands. According to long-term satellite studies, megaherbivores also exhibit considerable variability in seasonal range fidelity, adjusting their spatial patterns in response to changes in weather patterns and other physical constraints over several years (Burton-Roberts et al., 2022). Livestock distribution is greatly linked to environmental conditions within each region, such as the soil, microclimate, and water sources within each zone. These factors determine the spatial distribution patterns for herds based on local environmental conditions (Almudhafar et al., 2024). Observations carried out from community rangelands have also confirmed these findings by providing a daily perspective to variations in herd movements in wet and dry seasons (Tapela et al., 2026). Additionally, these patterns do not operate in isolation but alongside other anthropometric variations and adaptation patterns in different ecological regions (Rajan & Chawla, 2024).

Modeling of such ecosystems has recently centered on the non-linear relationship between climatic factors and biomass production. Modeling studies have shown how highly variable precipitation impacts the balance between forage regrowth and consumption rates in arid ecosystems (Nketsang et al., 2025). Selection models have been instrumental in explaining this concept through demonstration of how wild ungulates select plants to consume depending on the decline in the quality of the forage available seasonally (Cheng et al., 2023). Remote sensing technology is commonly applied in understanding such dynamics through observation of the overall climatic factors that affect the movement pattern of both wild and domesticated ungulates within savanna ecosystems (Rumiano et al., 2020). Such spatial dynamics are highly dependent on seasonally variable diets that allow for an increased ecological niche of savanna herbivorous species (Staver & Hempson, 2020).

It is possible to observe the impacts of such spatiotemporal modifications on herd structures in the form of fragmented landscapes. Research on mammal herbivores in multipurpose conservation areas showed distinct differences in terms of temporal and spatial variations in group sizes, with the herbivores tending to assemble themselves in large groups where food sources were concentrated (Leweri et al., 2022). GPS analysis of animal movements revealed that both livestock and wild herds were characterized by considerable spatial and temporal variation of resources and behavioral states, while the forage patches became drier (Liao et al., 2018). Lastly, modeling shows that the choice of path for modern herbivore movement is influenced by a number of factors other than just food availability, namely surface water locations, terrain, and anthropogenic impact (Boult et al., 2019).

Materials and Methods for Tracking Herbivore Adaptations

For accurate quantification of herbivore behavior in semi-arid environments in response to varying resources, the current study uses an extensive multi-faceted approach that employs remote sensing for plant growth, the use of GPS satellite tracking, and field observations of herbivore behavior. Fieldwork was carried out in a sample semi-arid savannah habitat featuring one long dry period running from May to October and one highly unpredictable wet period from November to April. Native grazers and cattle were the key species of focus in order to comprehensively understand the use of rangelands. Remote sensing was used through NDVI satellite images to estimate landscape vegetation and plant biomass at the level of individual patches across the study area.

The spatial movement data was collected using the GPS-telemetry collars that were specially made and designed to obtain accurate coordinates from the tagged animals in one-hour intervals. This information was further analyzed in order to obtain the trajectory of each animal. The calculation of the step length (the linear distance covered between two successive fixes), as well as the turning angle (angle formed at each intersection point), helped determine any changes in the behavioral state of the individual. At the same time, in parallel, the group surveys based on the vehicle were done twice a week following predefined regional transects. A "group" was characterized as a cluster of individuals showing synchronized behavior with a maximum inter-individual distance of fifty meters.

Figure 1 presents an example of the non-linear nature of climatic change and its effects on population responses. It demonstrates how varying water conditions affect the productivity of rangelands, which in turn affects spatial movements and social group sizes to meet their nutritional needs without violating water limitations.

The relationship between environmental factors and behavioral responses of herbivores was analyzed through the use of a non-mathematical formula. The behavior changes in the form of variations in movement velocity (V) per day as a function of D (distance to surface water), B (vegetative biomass), were formulated as per equation (1).

$$V(D,B) = \alpha \cdot e^{-\beta D} + \gamma \cdot ln(B+1) \qquad (1)$$

In this formula, α , β, and γ represent empirically derived scaling constants that adjust for species-specific movement capacities. To complement this spatial equation, the structural shifts in herbivore group sizes across changing rangeland conditions were analyzed.

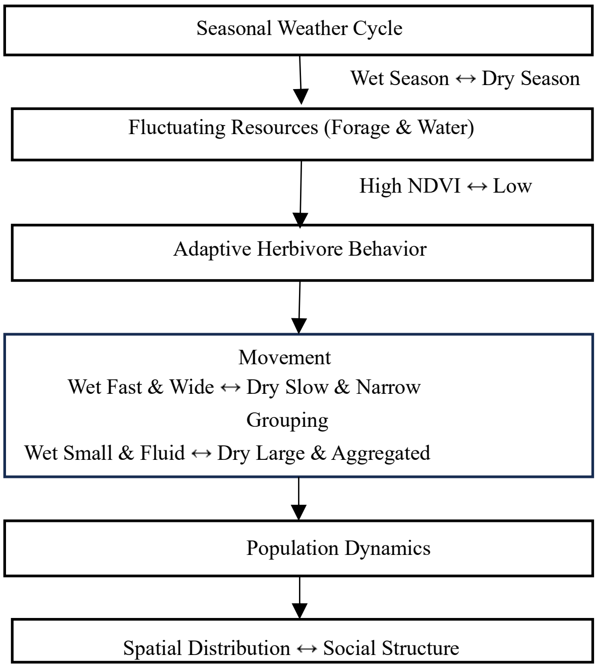

Figure 1: Conceptual Framework of Seasonal Resource Dynamics and Adaptive Herbivore Responses

Results

The results of the empirical study carried out over the course of the year have shown a radical change in the patterns of behavior of herbivores in terms of their space use and social structure from the wet to the dry period. While the wet period saw the spread of highly productive areas, as well as numerous ephemeral water pans in the landscape, the speed of daily movements and the size of home ranges increased significantly for the herbivores. The results of step-length analysis showed that herbivore herds used large step lengths due to continuous foraging in the area. At the onset of the dry period, however, all tracking ceased. As ephemeral water sources dried up, movement occurred along narrow corridors around boreholes and river beds.

Social organization, too, went through a parallel process of change, going from more open and spread-out forms to being resource-based and denser. In the wet season, the social groupings demonstrated fission-fusion dynamics, breaking down into smaller units that dispersed to search for food resources without competition in their immediate surroundings. In the dry season, there was no such flexibility. Individuals had to gather into large multi-family aggregations to make use of the scarce resource pools and water locations available. Aggregating is therefore a trade-off; the individuals are choosing to put themselves into situations of increased competition and stress as a means of gaining access to critical hydrological resources (Table 1).

Table 1: Seasonal Changes in Herbivore Spatial and Social Performance Metrics

Environmental & Behavioral Parameter	Wet Season Spectrum (NDVI > 0.45)	Dry Season Spectrum (NDVI ≤ 0.45)	Statistical Significance Value (p-value)
Mean Daily Step Length (km/day)	6.84 ± 0.72	3.12 ± 0.45	< 0.001
Average Social Group Size (Individuals)	12.4 ± 2.1	48.6 ± 8.3	< 0.001
Home Range Exploitation Area (km²)	142.5 ± 15.3	34.8 ± 4.1	< 0.01
Mean Distance to Permanent Water (m)	3,450 ± 210	420 ± 65	< 0.001
Daily Fission-Fusion Event Rate (Frequency)	4.8 ± 0.6	0.9 ± 0.2	< 0.001
Foraging Path Tortuosity Index (0–1)	0.34 ± 0.05	0.81 ± 0.09	< 0.01

Discussion

Based on the findings, it is evident that variations in the availability of resources determine both the spatial patterning and social dynamics of large herbivores in semi-arid environments. In addition, the decline in average step lengths as well as home range size in the dry season clearly illustrates the severe limitations that herbivores face owing to drought conditions. Instead of free roaming, herbivore populations are bound by a biological tether associated with permanent sources of water. This creates a biosphere-like phenomenon characterized by high levels of animal density in areas close to vital sources of water. High concentrations of animals may contribute to the rapid degradation of rangelands.

This constraint plays an essential role in creating the differences in the structure of the groups of herbivores. The transition from small, flexible foraging bands during the rainy season to larger, stable aggregations in drought conditions becomes a matter of forced adaptation of herbivores to the patchiness of the landscape. Although there are clear benefits of being part of a large group near dangerous waterholes, large aggregations become problematic from an ecological perspective. The high level of density near the waterholes creates greater competition, lowers the efficiency of feeding by individuals, and raises the chances of parasite/pathogen density-related transfer. Mixed areas of conservation and pasturage present an especially big danger for disease spillover cases due to close contact of wild ungulates with domestic animals.

Moreover, this adaptive behavior is being put under additional strain due to the growing trend towards global environmental disruption and habitat fragmentation. With changing precipitation patterns and drought becoming an increasing problem, the temporary water pans utilized by migrating animals during the wet season will cease to exist as quickly, or even may not exist at all. The result is a shift in the structure and an increasingly greater dependency on permanent water sources, resulting in further rangeland degradation in biosphere zones and the increased threat of starvation from depleted local vegetation. At the same time, the presence of human-made infrastructure such as fence lines, roads, and farming can create physical barriers to the natural migratory paths, thereby eliminating any ability of migrating herbivores to leave their drought zones.

Field Management Guide

In order to facilitate the work of those who seek to employ the information provided in conservation practice, park rangers and stockmen alike, the checklist below provides a systematic approach towards conducting range utilization studies and identifying potential problems before they arise.

Phase 1: Pre-Transient Mapping and Satellite Calibration

Before commencing with the field survey, obtain images through the use of a high-resolution satellite image of the entire management zone. The normal software used for the generation of the greenness map will help to identify locations whose vegetation index falls below the critical point. The landscape is divided into management zones according to the availability of permanent sources of water in the region.

Phase 2: Standardized Mobile Field Transects

Conduct vehicle or horseback surveys twice a week during early mornings and late afternoons when herbivores are most active. Travel at a consistent speed while on set pathways, and use precise rangefinders to determine the distance and bearing of each herd seen. In each herd survey, keep note of the total number of animals, their behaviors (whether they were eating, moving around, resting, etc.), and collect plant samples from the environment.

Phase 3: Analytical Threshold Auditing and Intervention

Weekly recording of field observations should be used to determine average group sizes and trends in relation to proximity to permanent water sources. In cases where the average size of herds is higher than the defined thresholds or where there is a decrease in the mean distances of animals to water sources, during the period of drought, adaptively manage through such practices as the introduction of temporary rotational water points to disperse the herds, reducing stocking density, or setting up temporary conservation areas within degraded pastures.

Conclusion

Through this study, it has been established that variations in the abundance and distribution of resources act as the main control mechanism of the movement ecology, space distribution, and social behavior of large herbivores in semi-arid habitats. It has been established that these herbivores adopt different, non-linear behavioral mechanisms in response to changes in the landscape. In situations when landscapes are abundant with resources, movement rates are relatively high and are characterized by low social density in order to maximize foraging efficiency. On the other hand, when resources are not abundant in the landscape, herbivores are forced to confine their movements in a relatively small area near permanent water sources, where they end up forming large herds, which increases the chances of disease transmission and competition. It can be seen that spatial plasticity plays an important role in the survival of these herbivores. Thus, management of such ecosystems calls for holistic approaches, which need to consider these changing behaviors. Fixed geographical approaches may fail to protect herbivores whose survival is based on landscape migration due to harsh weather cycles. Improperly designed fencing or alteration of land use can interfere with these evolutionary mechanisms, amplify the effects of climate change, and lead to further degradation of rangelands. In the future, scientists need to direct their efforts towards investigating these behavioral responses at extended timescales and different environments. Specifically, there is an immediate need for studies addressing the long-term effects of multiannual drought cycles on behavioral plasticity and the particular environmental factors that drive irreversible changes in home range fidelity. The use of detailed microclimatic observations along with modern tracking technologies will help us better anticipate behavioral responses to the fragmentation of grazing lands. The results of such research would allow ecologists and conservationists to formulate more effective policies that will preserve not only dryland fauna but also the communities relying on these ecosystems.

References

[1] Almudhafar, Rusul Z., Safaa M. Almudhafar, and Basim A. Almayahi. "Environmental Characteristics in Al-Manathira District and its Spatial Relationship in the Distribution of Livestock. " *Archives for Technical Sciences* 2, no. 31 (2024): 359-367. https://doi.org/10.70102/afts.2024.1631.359

[2] Boone, Randall B., Shauna B. Burnsilver, Jeffrey S. Worden, Kathleen A. Galvin, and N. Thompson Hobbs. "Large-Scale Movements of Large Herbivores Livestock following changes in seasonal forage supply." In *Resource ecology*, pp. 187-206. Springer, Dordrecht, 2008. https://doi.org/10.1007/978-1-4020-6850-8_16

[3] Boult, Victoria L., Richard M. Sibly, Tristan Quaife, Vicki Fishlock, Cynthia Moss, and Phyllis C. Lee. "Modelling large herbivore movement decisions: Beyond food availability as a predictor of ranging patterns." *African Journal of Ecology* 57, no. 1 (2019): 10-19. https://doi.org/10.1111/aje.12553

[4] Burton-Roberts, Rhea, Line S. Cordes, Rob Slotow, Abi Tamim Vanak, Maria Thaker, Navashni Govender, and Graeme Shannon. "Seasonal range fidelity of a megaherbivore in response to

environmental change." *Scientific Reports* 12, no. 1 (2022): 22008. https://doi.org/10.1038/s41598-022-25334-8

[5] Cheng, Hua, Bao-Cheng Jin, Kai Luo, Xue-Li Zhang, Jiu-Ying Pei, Yong-Hong Zhang, Li-Qin Han et al. "Seasonal resource selection of free-ranging Zhongwei goats in the semi-arid grassland." *animal* 17, no. 10 (2023): 100972. https://doi.org/10.1016/j.animal.2023.100972

[6] Leweri, Cecilia M., Gundula S. Bartzke, Maurus J. Msuha, and Anna C. Treydte. "Spatial and seasonal group size variation of wild mammalian herbivores in multiple use landscapes of the Ngorongoro Conservation Area, Tanzania." *PLoS One* 17, no. 4 (2022): e0267082. https://doi.org/10.1371/journal.pone.0267082

[7] Liao, Chuan, Patrick E. Clark, Mohamed Shibia, and Stephen D. DeGloria. "Spatiotemporal dynamics of cattle behavior and resource selection patterns on East African rangelands: evidence from GPS-tracking." *International Journal of Geographical Information Science* 32, no. 7 (2018): 1523-1540. https://doi.org/10.1080/13658816.2018.1424856

[8] Martin, Jodie, Simon Benhamou, K. Yoganand, and Norman Owen-Smith. "Coping with spatial heterogeneity and temporal variability in resources and risks: adaptive movement behaviour by a large grazing herbivore." *PloS one* 10, no. 2 (2015): e0118461. https://doi.org/10.1371/journal.pone.0118461

[9] Nketsang, Thabo S., Semu Mitiku Kassa, Moatlhodi Kgosimore, and Gizaw Mengistu Tsidu. "Understanding the Impacts of Rainfall Variability on Natural Forage–Livestock Dynamics in Arid and Semi-Arid Environments." *Applied Sciences* 15, no. 7 (2025): 3918. https://doi.org/10.3390/app15073918

[10] Rajan, Vinod, and Roshni Chawla. "Anthropometric Variations and Adaptations across Diverse Ecological Zones." *Progression journal of Human Demography and Anthropology* (2024): 1-4.

[11] Reginald, P. Joshua. "Climate Change–Driven Zoonoses: Predictive Modeling and Adaptive Risk Mitigation in Pastoral Systems." *National Journal of Animal Health and Sustainable Livestock* 2, no. 2 (2024): 34-41.

[12] Rumiano, Florent, Elodie Wielgus, Eve Miguel, Simon Chamaillé-Jammes, Hugo Valls-Fox, Daniel Cornélis, Michel De Garine-Wichatitsky, Hervé Fritz, Alexandre Caron, and Annelise Tran. "Remote sensing of environmental drivers influencing the movement ecology of sympatric wild and domestic ungulates in semi-arid savannas, a review." *Remote Sensing* 12, no. 19 (2020): 3218. https://doi.org/10.3390/rs12193218

[13] Staver, A. Carla, and Gareth P. Hempson. "Seasonal dietary changes increase the

abundances of savanna herbivore species." *Science Advances* 6, no. 40 (2020): eabd2848. https://doi.org/10.1126/sciadv.abd2848

[14] Tapela, M. H., M. I. Samuels, C. F. Cupido, A. Finca, T. C. Zondani, and A. Engelbrecht. "Daily herd movements across the wet and dry season in the semi-arid communal rangelands of Namaqualand, South Africa." *African Journal of Range & Forage Science* 43, no. 1 (2026): 81-96. https://doi.org/10.2989/10220119.2026.2628180